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ECOLOGICAL EVALUATION OF TWO PRAWN CULTURE FIELDS IN THE COCHIN BACKWATER BASED ON PREMONSOON DIURNAL OBSERVATIONS

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ABSTRACT

Extensive low lying areas of the Cochin Backwater peripheries at its lower reaches are bunded into interconnected ponds for paddy-cum-prawn culture. Results of a study of two representative ponds are reported.

The ponds under study were found to be rich in nutrients and primary production and have a detritus dominated simple food chain aided by a substratum predominantly of fine sand, silt and clay, rich in organic content and benthos. These shallow, semienclosed systems have temperature between 29° and 35°C during the main prawn culture season from December to April and provide ecological conditions distinct in many respects from that of the main backwater. They are given a high rating in terms of their suitability for culture of prawns as these ponds are maintained in the autotrophic range with a P/R ratio greater than one under high production and respiration rates. Previous authors found a higher P/R ratio for the main backwater system, but without fulfilling the latter condition. The present study confirms the need to give full recognition to both these parts of the backwater in planning detailed ecological studies in order to fully utilise the high aquaculture potential afforded by the Cochin Backwater.

INTRODUCTION

THE EXTENSIVE Cochin Backwater and its intricate system of canals, with its main freshwater source from Moovattupuzha and Periyar Rivers and tidal flow and flushing through the main Cochin Harbour entrance and to a lesser extent through the Azhikode entrance 26 km north, is a unique body of water providing highly varying environmental conditions to its biota. Since the backwater with its maize of canals is located in a low-lying area, extensive regions are bunded into well-laidout inter-connected ponds for perennial prawn culture or seasonal paddy-cum-prawn culture purposes. Since these shallow ponds of 1 to 2 m depth are semi-enclosed systems with only narrow connections to the backwater, often through smaller canals, a partially land-locked state prevail here due to lack of free mixing and inter-change with the main backwater system. Since these ponds provide the mainstay for the fishermen for extensive culture of prawn, ecological study of these ponds is important for assessing and augmenting the potential of the Cochin Backwater as an ecosystem – a fact poorly recognized as evidenced by the dearth of such information. Recently, some authors (Balachandran *et al.*, 1980; Sankaranarayanan *et al.*, 1982; Nair *et al.*, 1988; Gopalakrishnan *et al.*, 1988) have studied the seasonal changes in the environmental and ecological characteristics of prawn culture fields around Cochin.

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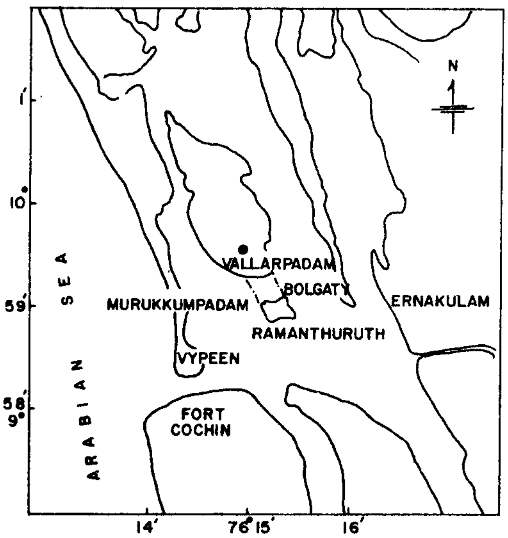

FIG. 1 a. The location of the ponds studied.

Materials and Methods

Two adjoining culture ponds with an average depth of 1 m at Vallarpadom Island (Fig. 1 a) were chosen as they were typical of many ponds in this region and because one of them (Pond I), the last in the series of ponds, is partially sheltered by trees and marginal vegetation and appeared more stagnant and eutrophic. In each pond, samples were always collected from the same location. Mud and water samples were collected at 3-hourly intervals and monitored for various environmental parameters. Phyto- and zooplankton samples were separately collected by filtering 15 litres of water from each pond during each sampling using 100 μm bolting silk.

A total of eighteen benthic samples were collected from each pond for macrofauna using a hollow perspex cylinder of 8.3 cm dia. The samples were collected each time in duplicate from each pond and sieved in a 0.5 mm sieve, sorted, counted and weighed. The nutrients were estimated using the methods described by Strickland and Parsons (1968), particulate organic carbon in the water and organic carbon in the mud by the wet-oxidation method of Wakeel and Riley (1957) and Chlorophyll *a* estimations by following the trichromatic method using Parsons and Strickland (1963) equations. Eh values were taken from 2100 hrs to 0900 hrs. Salinity, temperature and pH were also measured along with the rest of the parameters.

An estimate of the community production and respiration was made from the dissolved oxygen curve (Redfield, 1948). Correction for the diffusion (D) across the air-water interface was made using the equation

$$D = K.S. \qquad \text{.........(1)}$$

where K is the gas transfer coefficient and S is the saturation deficit between water and air. The K was calculated by using the equation

$$K \; \frac{Z\,(q_1 - q_2)}{(s_1 - s_2)} \qquad \text{.........(2)}$$

where Z is the mean depth, which for the wind mixed shallow ponds under study is unity, q1 and q2, the rates of changes of oxygen during two consecutive 3 hour intervals and s1 and s2 are saturation deficits for the same period calculated from the equations of Redfield (1948) using the oxygen saturation values obtained from the compilation made by Weiss (1970). A conversion factor $\frac{0.536}{PQ}$ was used for converting the oxygen values to productivity, where PQ = 1.2 (Strickland, 1960).

RESULTS

Physico-chemical Parameters

Temperature : Diurnal variation in temperature was of the order of 5.8 and 5.2°C in Pond I and II respectively. This is considerably in excess of the annual range of 3.4°C observed by Qasim *et al.* (1969) for the surface waters of the Cochin Backwater, but is slightly less than the estimate of 6.5°C recorded by Sankaranarayanan *et al.* (1982) in some tidal ponds in Ramanthuruthu Island which is closely situated to the island where the present study was undertaken. The minimum and maximum values were 29.8 and 35.8°C. Both the temperature minima and maxima were significantly higher than the corresponding values of 28.4 and 31.8°C recorded by Qasim *et al.* (1969) and is therefore expected to exert a corresponding influence on the various metabolic activities at different trophic levels in the pond. Generally prawns are often observed to segregate in deeper water having lower temperature and this is particularly shown by the larger prawns towards the end of the prawn culture season in April when the temperature often exceeds 35°C.

Salinity : Salinity remained more or less steady between 28 and 28.5% in Pond I and around 29.5% in Pond II. The salinity is slightly lower in Pond I and the higher values observed during 1500 and 1800 hours in this pond is due to the presence of more saline water at the sampling site coming from Pond II during the high tide period through a closely located partial connection (Fig. 1 b) before it is more evenly distributed.

pH : The pH values in both ponds varied between 7 and 8 and followed closely the oxygen curve showing a correlation with the intensity of primary production. The estimations of the pH in the mud remained around 7.

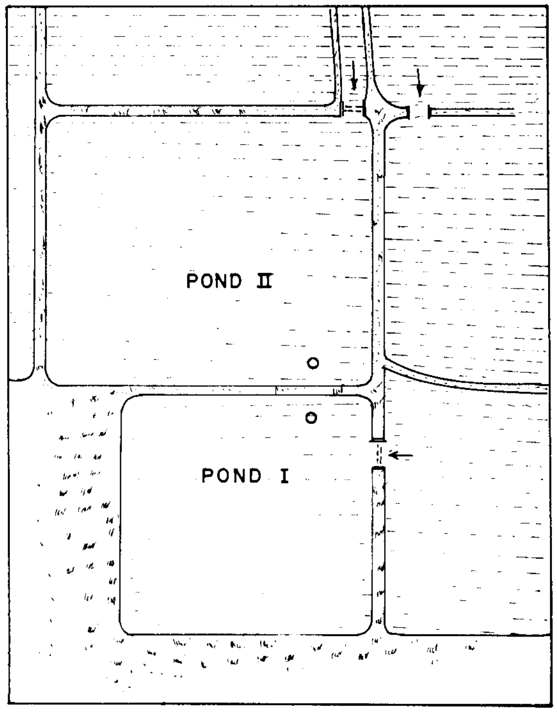

FIG. 1 b. **Diagrammatic sketch of the pond showing the marginal vegetation and the partial connection between the two ponds.**

Eh : Estimation of Eh for the water were always positive ranging from +50 to +175 and negative for the mud with values between -150 and -290. No significant pond-wise variation was noticed. As mentioned earlier redox potential could not be measured during day time.

Oxygen : The diurnal distribution of oxygen values showed the typical pattern ranging from 0.5 to 8.9 ml/l^{-1} in Pond I and from 0.1 to 7.08 ml/l^{-1} in Pond II with high values during day time.

TABLE 1. *Grain size distribution in the sediment*

Pond		Sand				Silt + Clay			
		Coarse sand (1000-500 µm)	Medium sand (500-250 µm)	Fine Sand (250-62 µm)	Total	Silt (62-4 µm)	Clay (< 4 µm)	% of silt + Clay	Total Sand + Silt + Clay
I	%Wt-g	0.0546	1.1131	12.2338	13.3814	7.51015	4.11285	11.623	25.0044
		0.1384	4.4522	48.9350	53.5256	30.0406	16.4514	46.492	100.0176
II	%Wt-g	0.0106	0.54115	11.6944	12.2461	9.35975	3.3905	12.7503	24.9963
		0.0424	2.1646	46.7874	48.9844	37.439	13.562	51.001	99.9854

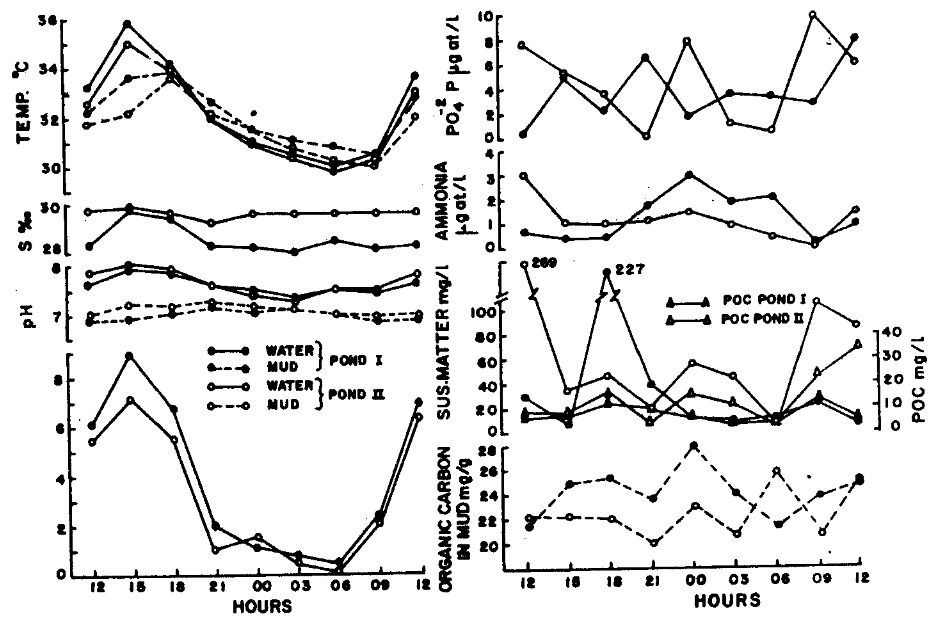

FIG. 2. Diurnal variations in physico-chemical parameters in Ponds I and II.

Nutrients : Phosphate concentration in water was fairly high in both the ponds and showed unexpected fluctuations with value varying from 0.52 to 7.81 µg at l^{-1} and from 0.10 to 9.42 µg at l^{-1} respectively for Ponds I and II. This appears to be largely due to variations in the suspended sediments in the water brought from the mud by wind mixing and was particularly noticeable in Pond II whereas in Pond I, sheltered by trees and marginal vegetation, this correlation was less evident (Fig. 2). The high concentration of the suspended matter in Pond I at 1800 hrs may as well be due to the disturbance caused by the influx of water from Pond II during the peak high tide period at the sampling site as also observed for salinity.

Nitrite and nitrate estimations could not be made from the field during the period of continuous observations since the necessary facilities could not be transported to the field. But the ammonia concentration was estimated and it was low in both the ponds with values around 1 μg at l^{-1} except during night time in Pond I in which the pattern of ammonia

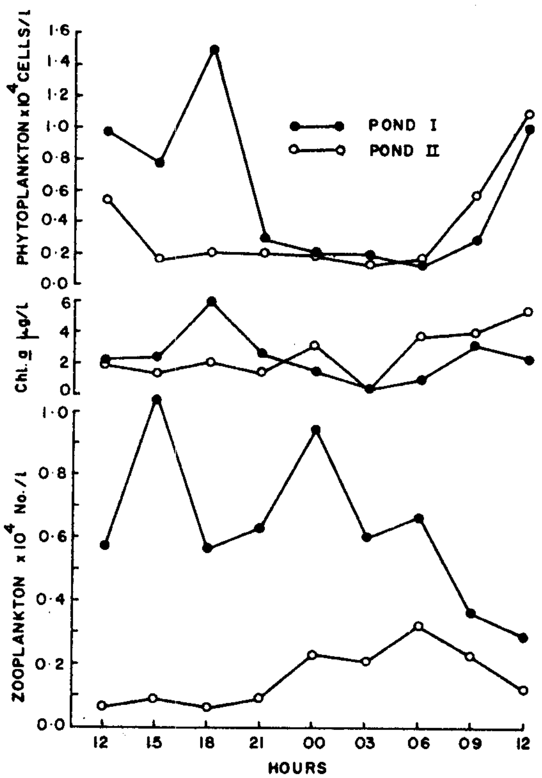

FIG. 3. Diurnal variations in Chlorophyll *a*, phytoplankton and zooplankton.

distribution suggests greater release of metabolic products compared to Pond II. Plankton and benthic biomass were also more in this pond (Table 2 and 3). A similar trend in ammonia was not seen in Pond II probably because of the lower plankton abundance and better mixing. However, the higher value of ammonia observed at noon in Pond I could not be interpreted from the available data. Diel ammonia profiles given by Warren Flint and Rabalais (1981) for the Texas Coast having similar substratum with high organic content also showed higher ammonia levels in surface water at noon.

TABLE 2. *Qualitative and quantitative abundance of phyto- and zooplankton*

Plankton	Pond I Number per lit.	Pond I Percen-tage	Pond II Number per lit.	Pond II Percen-tage
Phytoplankton				
Diatoms				
Pleurosigma spp.	539	9.09	806	23.35
Gyrosigma sp.	70	1.18	56	1.62
Nitszchia sp.	160	2.70	209	6.05
Navicula sp.	363	6.12	417	12.08
Biddulphia sp.	85	1.43	17	0.49
Diploneis sp.	69	1.16	54	1.56
Caloneis sp.	46	0.78	29	0.84
Triceratium sp.	20	0.34	44	1.27
Cyanophyceae				
Oscillatoria sp.	1,497	25.26	379	10.98
Chlorophyceae				
Chlorosigma sp.	25	0.42	62	1.80
Dinoflagellates				
Peridinium sp.	2,980	50.28	1,329	38.50
Ceratium sp.	73	1.23	50	1.45
Total	5,927	99.99	3,452	99.99
Zooplankton				
Nauplii	3,227	54.28	586	37.40
Rotifer	1,254	21.09	623	39.76
Calanoid Copepod	769	12.94	213	13.59
Cyclopoid Copepod	589	9.91	145	9.25
Gastropod larva	106	1.78		
Total	5,945	100.00	1,567	100.00

Suspended matter : Fig. 2 shows high values of suspended matter in the water as also wide variations in it during the period of observations. Particulate organic carbon was more in Pond II with values ranging from 3 mg Cl^{-1} to 34.2 mg Cl^{-1} whereas in Pond I they were found to lie between 3 mgC l^{-1} and 13.2 mgC l^{-1}. The contribution from phytoplankton to the POC calculated from chlrophyll *a* values using the conversion factor given by Laevastu (1956) was comparatively small and was only of the order of 0.4% and 0.3% respectively for the two ponds.

TABLE 3. *Composition and average abundance of macrobenthos in Ponds I and II*

Benthos	Pond I					Pond II				
	Adults (No. m^{-2})	Young ones (No. m^{-2})	Ratio of young ones to adults	Total (No. m^{-2})	Biomass (g m^{-2})	Adults (No. m^{-2})	Young ones (No. m^{-2})	Ratio of young ones to adults	Total (No. m^{-2})	Biomass (g m^{-2})
Tanaidacean										
Apseudes chilkensis	4,530	1,815	0.4007	6,345 (61.80)	4.9635 (16.82)	8,792	4,983	0.5673	13,780 (48.78)	10.5625 (54.05)
Apseudes gymnophobia	367	329	0.8965	696 (6.78)	0.0244 (0.08)	509	706	1.3770	1,215 (4.30)	0.09925 (0.45)
Amphipods										
Eriopsis chilkensis	675	508	0.7525	1,183 (11.52)	0.7934 (2.69).	4,780	3,704	0.7749 (30.04)	8,484 (30.04)	3.86330 (19.77)
Macra othonides	1,063	364	0.3424	1,427 (13.90)	0.564 (1.91)	2,384	2,268	0.9513	4,652 (16.47)	0.802 (0.410)
Polychaetes	288	207	0.7188	495 (4.82)	15.077 (57.10)	81	35	0.4321	116 (0.41)	4.2269 (21.63)
Gastropods	121	—	—	121 (1.18)	8.085 (27.42)	—	—	—	—	—
Total				10,267	29.5073				28,247	19.5439

NB : Values given in parenthesis are percentages.

Organic carbon in mud : The organic carbon in the mud was higher in Pond I (21.06 - 27.66 mgC gm^{-1} mud) than in Pond II (19.79 - 25.57 mgC gm^{-1} mud). The corresponding mean values were 24.03 and 22.25 mgC gm^{-1} mud. The range in the estimates of organic carbon in mud may be due to sampling variations.

Substratum : Grain size analysis of the mud based on 9 samples from each Pond (Table 1) showed that fine sand, silt and clay formed the major component of the substratum and is typical of many of these culture fields as also noted by Aravindakshan *et al.* (1992). The organic content of the mud, amounting respectively to 4.14% and 3.84% by weight was also high in the two ponds. This substratum appears to be favourable for maintaining high benthic biomass. Aravindakshan *et al.* (1992) recorded a benthic biomass of about 50 gm m^{-2} in certain culture fields in the Cochin Backwater and is considerably in excess of the values obtained during the present study.

Biological factors

Phytoplankton : Phytoplankton was largely represented by diatoms, dinoflagellates and cyanophyceae. Their relative abundance, total count and other parameters are given in Table 2 along with that of zooplankton. The three hourly estimates of chlorophyll *a* and the total phytoplankton counts in both ponds showed high correlation when tested by Kendall's T_b (Kendall, 1962) with respective values of 0.71 and 0.76. But the ratio of average value of chlorophyll *a* to average total phytoplankton count was significantly high for the Pond II suggesting that the phytoplankton in this pond is photosynthetically more active. The respective values for the two ponds were 0.0006 (Pond I) and 0.0013 (Pond II). The diel variation in chlorophyll *a* and total phytoplankton count given in Fig. 3 showed a marked decline during the night.

Zooplankton : A clear pattern in the diurnal distribution of zooplankton is not seen from Fig. 3 perhaps because the ponds are too shallow. In both ponds few taxa constituted the zooplankton, each represented again only by a few species. However, they were distinctly more abundant in Pond I (Table 2). Their greater abundance along with the presence of large number of copepod nauplii and even gastropod larvae despite their modest representation in the benthos suggest much less predation of zooplankton than in Pond II. The penaeid prawns and fishes such as *Etroplus* sp. and *Tilapia* sp. being mainly bottom feeders, predation of zooplankton in these ponds may be by benthic forms like amphipods that make sporadic appearance into the water column. These were well represented in Pond II, but not in Pond I. Larger amphipods such as *Eriopisa chilkensis* may use their chelae for catching their food organisms while the smaller species like *Maera orthonoides* largely depend on the current generated by their pleopods.

Benthos : Table 3 shows the composition and average abundance of benthos in the two ponds. As in zooplankton, benthos was also represented only by a few groups and species, but they were all highly preferred food organisms of prawns (Balasubramanian *et al.,* 1979). While both the ponds supported rich benthic biomass with 29.51 and 19.54 gm m^{-2}, the ratio between juveniles and adults for most of the species was higher for Pond II than for Pond I as also their individual contribution to the total benthic biomass except in the case of polychaetes which showed a higher ratio, numerical abundance as well as biomass in Pond I. Gastropods were seen in small numbers in Pond I, but were not represented in Pond II. The polychaetes and gastropods were responsible for the higher biomass in Pond I. However, phytoplankton abundance along with greater cholorophyll - phytoplankton ratio, zooplankton and the benthic composition indicate a more balanced biota in Pond II with a better predator - prey relation between successive trophic levels.

Discussion

Among all the parameters studied diurnal variations in temperature, dissolved oxygen, gross primary production and community respiration were found to be most helpful to provide a meaningful interpretation of the pond metabolism. Information collected on qualitative and quantitative aspects of phyto- and zooplankton provided additional information in assessing their efficiency.

Both the gross production and respiration were found to be high for both ponds. After correction for diffusion, gross production amounted to 5.68 gmC m^{-2} day^{-1} and 6.21 mgC m^{-2} day^{-1} for Ponds I and II and the corresponding community respiration being 3.545 and 3.48 mgC m^{-2} day^{-1} with a net production of 2.13 and 2.73 gmC m^{-2} day^{-1}. The P/R ratios were in the autotrophic range (Odum, 1960) with values 1.6 and 1.74 for the two ponds. Although the P/R ratio of 2.9 was noticed by Qasim *et al.* (1969) for April, their gross production and respiration values were only 1.85 gmC m^{-2} day^{-1} and 0.64 gmC m^{-2} day^{-1}. The high values of gross production obtained for the ponds were comparable to the figures given by Nair and Pillai (1969). Qasim *et al.* (1972) and Balasubramanian and Wafar (1974) for coral reef environments in the Palk Bay and Lakshadweep region, but the high values of community respiration seen in the ponds were similar to those for mangrove swamps and sea grass beds recorded by Untawale *et al.* (1977) for heterotrophic mangrove swamps and Balasubramanian and Wafar (1975) for autotrophic sea grass beds. These ponds are thus unique in having high gross production and respiration with P/R ratio maintained at the autotrophic range whereas in the other environments cited above P/R ratio was either highly autotrophic or heterotrophic. The community metabolism is thus maintained at the near optimum level in both the ponds and the data did not provide any evidence of organic load in Pond I. Fairly high temperature, nutrients, high primary and benthic production and efficient wind mixing in these shallow ponds keep the level of ammonia and other toxic metabolities at a relatively low level and thus help to maintain these ponds at the autotrophic range despite the large biomass maintained by the ponds. High stocking rate of juvenile prawns is thereby possible in these ponds as also found by Gopalan *et al.* (1982). Although oxygen curves in Fig. 2 show a steady decline during the night, the low level of oxygen is seen only for a brief period.

Qasim *et al.* (1969), Qasim (1970), Sankaranarayanan *et al.* (1982), Balachandran *et al.* (1980) and Gopalakrishnan *et al.* (1988) have also found that the food web in the Cochin Backwater is relatively simple with a major share of phytoplankton and other dead and decaying matter directly contributing to the production of benthos with zooplankton playing a less vital role in the food chain. Enormous abundance of A. chilkensis (upto 11,458 m^{-2}) were observed in the ponds in the nearby Ramanthuruthu Island (unpublished) which were recorded by Balasubramanian *et al.* (1979) as a highly preferred food of penaeid prawns. Similar environmental and biological characteristics of many ponds in certain regions in the Cochin Backwater (Paulinose *et al.* (1981) thus make them some of the best prawn culture fields in the world such as that recorded by Hall (1962) and others in Southeast Asia. More detailed studies on pond metabolism that make these ponds so unique for prawn culture are underway.

REFERENCES

ARAVINDAKSHAN, P. N., T. BALASUBRAMANIAN, C. B. L. DEVI, K. K. C. NAIR, T. C. GOPALAKRISHNAN, K. V. JAYALAKSHMY AND M. KRISHNANKUTTY 1992. Studies on the benthos and substratum characteristics of prawn culture fields in and around the Cochin Backwater. *J. mar. biol. Ass. India,* **34** (1 & 2) : 203-217.

BALACHANDRAN, T., C. B. LALITHAMBIKA DEVI, T. C. GOPALAKRISHNAN AND M. KRISHNANKUTTY 1980. On the availability of food for prawns in some tidal ponds of Cochin Backwater at Ramanthuruth. *Abstract No.* 222, *Mar. biol. Ass. India, Symp. Coastal Aquaculture, Cochin, India,* p. 422.

BALASUBRAMANIAN, T. AND M. V. M. WAFER 1974. Primary productivity of some fringing reefs of Southeast India. *Mahasagar, Bull. natn. Inst. Oceanogr.,* **7** (3 & 4) : 157-164.

——— AND ——— 1975. Primary productivity of some sea grass beds in the Gulf of Mannar. *Ibid.,* **8** (1 & 2) : 87-91.

———, C. B. L. DEVI AND M. KRISHNANKUTTY 1979. Feeding behaviour and preying efficiency of *Metapenaeus dobsoni. Indian J. Mar. Sci.,* **8** (3) : 197-199.

GOPALAN, U. K., K. S. PURUSHAN, V. SANTHAKUMARI AND P. P. MEENAKSHI KUNJAMMA 1982. Experimental studies on high density, short term; farming of shrimp *Penaeus indicus* in Pokkali field in Vypeen Island, Kerala, *Proc. Symp. Coastal Aquaculture, MBAI,* 1 : 151-159.

GOPALAKRISHNAN, T. C., C. B. L. DEVI, P. N. ARAVINDAKSHAN, K. K. C. NAIR, T. BALASUBRAMANIAN AND M. KRISHNANKUTTY 1988. Phytoplankton and Zooplankton of some paddy-cum-prawn fields in and around Cochin. *Mahasagar, Bull. natn. Inst. Oceanogr.,* **21** (2) : 85-94.

HALL, D. N. F. 1962. Fishery Publication, London (Her Majesty's Stationery Office), **17**.

KENDALL, M. G. 1962. *Rank correlation methods.* Charles Griffin and Company, London. 3rd Edition.

LAEVASTU, T. 1956. FAO/57/7 : 4472.

NAIR, K. K. C., V. N. SANKARANARAYANAN, T. C. GOPALAKRISHNAN, T. BALASUBRAMANIAN, C. B. L. DEVI, P. N. ARAVINDAKSHAN AND M. KRISHNANKUTTY 1988. Environmental conditions of some paddy-cum-prawn culture fields of Cochin Backwaters, Southwest coast of India. *Indian J. Mar. Sci.,* **7** (1) : 24-30.

NAIR, P. V. R. AND C. S. G. PILLAI 1969. Corals and Coral Reefs. *Proc. Symp. Corals and Coral Reef. MBAI.* pp. 12-33.

ODUM, E. P. 1960. Algae and metropolitan waters (Transactions of the 1960 Seminar) E. S. Dept. Health Education and Welfare. Robert A. Taft, Sanitary Engineering Centre, Cincinnati.

PARSONS, T. R. AND J. D. H. STRICKLAND 1963. Discussion of spectrophotometric determination of marine plant pigments, with revised equations for ascertaining chlorophylls and carotenoids. *J. mar. Res.,* **21** : 155.

PAULINOSE, V. T., T. BALASUBRAMANIAN, P. N. ARAVINDAKSHAN, P. GOPALA MENON AND M. KRISHNANKUTTY 1981. Some aspects of prawn ecology in Cochin Backwaters. *Mahasagar, Bull. natn. Inst. Oceanogr.,* **14** (2) : 123-133.

QASIM, S. Z., S. WELLERHAUS, P. M. A. BHATTATHIRI AND S. A. H. ABIDI 1969. Organic production in a tropical estuary. *Proc. Indian Acad. Sci.,* **69** : 51-94.

——— 1970. Some problems related to the food chain in tropical estuary. *In* : J. H. Steele [Ed.] *Marine Food Chains.* Oliver Boyd, Edinburgh; pp. 45-51.

———, P. M. A. BHATTATHIRI AND C. V. G. REDDY 1972. Primary production of an atoll in the Laccadives. *Int. Rev. Ges. Hydrobiol.,* **57** (2) : 207-225.

REDFIELD, A, C., 1948. The exchange of oxygen across the sea surface. *J. Mar. Res.,* **7** : 347-361.

SANKARANARAYANAN, V. N., S. KUMARAN, T. BALASUBRAMANIAN, ROSAMMA STEPHEN AND S. U. PANAMPUNNAYIL 1982. Studies on the environmental conditions of tidal ponds in the Ramanthuruth Island, Cochin. *Proc. Symp. Coastal Aquaculture,* 1 : 362-368.

STRICKLAND, J. D. H. 1960. Measuring the production of marine Phytoplankton. *Bull. Fish. Res. Bd. Canada.,* **122** : 172 p.

——— AND T. R. PARSONS 1968. A Practical Handbook of seawater analysis. *J. Fish. Res. Bd. Canada, Ottawa,* **167**.

UNTAWALE, A. G., T. BALASUBRAMANIAN AND M. V. M. WAFAR 1977. Structure and production in a detritus - rich estuarine mangrove swamp. *Mahasagar, Bull. natn. Inst. Oceanogr.,* **10** (3 & 4) : 173-177.

WARREN FLINT, R. AND N. N. RABALAIS 1981. Environmental studies of a marine ecosystem - South Texas outer continental shelf. *Univ. Texas Press.*

WAKEEL, S. K. AND J. P. RILEY 1957. The determination of organic carbon in marine muds. *J. Cons. Int. Explor. Mer.,* **22** : 180-183.

WEISS, R. F. 1970. The solubility of nitrogen, oxygen and argon in water and seawater. *Deep Sea Res.,* **17** : 721-735.